# Batch Bayesian optimization of attosecond betatron pulses from laser wakefield acceleration

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Laser wakefield acceleration [1] generates broadband X-ray femtosecond-scale radiation, commonly referred to as betatron radiation. This radiation is produced by pC-class electron bunches accelerated to relativistic energies via a plasma wakefield wave driven by an ultrashort laser pulse. The accelerated electron beam undergoes transverse oscillations, emitting the betatron radiation. Due to the micrometer scale of the source, betatron radiation is particularly well-suited for advanced imaging techniques, such as diffraction and phase-contrast imaging. Recent advances in laser technology have extended these capabilities into the attosecond regime. The practical applications of this source would significantly benefit from an increase in photon generation.

Previous simulations showed that sub-femtosecond betatron pulses can be generated by 10-mJ fs-class laser pulses [2]. In this work, we optimize the plasma density profile based on numerical particle-in-cell simulations. We apply batch Bayesian optimization, a method that iteratively adjusts input parameters based on a surrogate model to efficiently explore the parameter space and identify the optimal conditions for photon production. Specifically, we introduce a short region of increased density, as shown in Figure 1, and optimize the placement, length, and peak density of this density spike to enhance the betatron radiation while keeping the pulse duration short. Batch Bayesian optimization successfully identified the region of betatron enhancement with respect to photon gain and located a region in parameter space. These conditions, which are experimentally feasible, improve photon yield by more than 350%, while maintaining the betatron X-ray pulse duration around 100 attoseconds. Our findings reveal that this increase in photon production is driven by an amplitude boost in electron oscillations, providing valuable insights into the underlying mechanisms.

With increasing photon number, the energy of the generated photons also increased, even though this factor was not explicitly included in the optimization process. These findings highlight the efficiency of the batch Bayesian approach for multiparametric scans, especially when the number of simulations is limited, the output is complex, or when time-intensive manual processing is required.

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References

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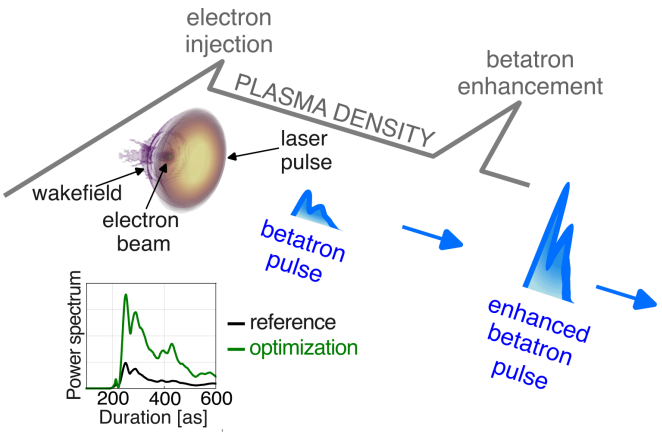


**Figure 1:** Set-up for the betatron enhancement and temporal profiles of the reference and optimized betatron pulses.